Method for Improved Efficiency and Reduced Energy Consumption of an Ion Motor

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Abstract

With the recent attention to environmental concerns, and as a result of progressive miniaturization, there has been an increasing demand for methods to cool electrical and electronic systems which do not depend on mechanical involvement. Ion motors, which avoid friction and the need for lubrication, are a potential solution to the problem. In this paper we will discuss factors affecting motor speed, and we will present solutions we have developed to increase speed while maintaining high efficiency.

Previous experiments showed that within a low to moderate range of applied voltage, ion velocity was linearly proportional to input power. However, as applied voltage emphasis neared peak voltage (breakdown voltage) there was an additional negative effect on ion velocity, caused by the development of an "ionic cloud." This ionic cloud contains static charges which impede the free flow of ionized air in the system.

The optimal solution was to use a two motor system. The first motor blows ionized air into the second motor, and both operate at relatively low voltages. Maximum "ionic cloud" dispersion was achieved by optimizing the distance between the two motors. Results showed a 60% increase in speed and an 80% decrease in power consumption of the motor compared to single motor systems.

This research offers the prospect of developing a high-power energy efficient ion motor for cooling or pumping systems. This will lead to significant energy savings and minimize environmental concerns.

1. Introduction

The first recorded scientific paper regarding the phenomenon of "ionic winds" was published in 1703[1]. For many years, researchers primarily focused on trying to utilize this effect for building ion engines (e.g. ionocraft) [2]. Recently, there has been a renewed interest in this phenomenon to build cooling devices for electronic equipment since ion motors do not have rotating parts which wear out [3]. The main obstacle has been reaching high flow speeds. In order to increase the speed of the ionized air, our group changed several factors: we increased the inter-electrode potential, optimized the distance between the electrodes, and increased the number of electrodes [3, 4, 5]. It was found that it is possible to achieve flow velocities equal to that of a mechanical fan (several meters a seconds) [6, 7].

It has been found that increasing the potential difference between the electrodes did not linearly increase the velocity of the ionized air. As the voltage approached the point of electrical breakdown of the air between the electrodes, the speed stopping rising. It was speculated that "ionic clouds" formed around the electrodes, impeding the flow of ionized air in the medium. Ion motors have been characterized as inefficient and their use has been limited [5].

The purpose of the current research is to test a multi-tier ion motor that would increase the velocity of the "ionic winds" and raise the efficiency of the ion motor. This research was done with a negative corona system, but the conclusions are valid for positive corona system as well.

2. Regional charge between the electrodes and dispersal methods

2.1 The structure of "ionic clouds"

When corona discharge takes place, the air surrounding the electrode is ionized and pushed forward. The strength of the electric field at the ionizing electrode decreases with the square of the distance from the electrode. Far from the electrode, electrons are neutralized by combination with positive ions, or they combine with neutral molecules to create negative ions. These negative ions create a barrier for the movement of the air ionized by the electrodes.

The average speed of the charged particles in the medium of an electric field (true for electrons and ions) is [9]:

$$v_p = \mu \cdot E \tag{1}$$

E - The electric field

μ - The permeability constant of charged particles

$\mu = 5 \cdot 10^{-2}, \ \frac{m^2}{V \cdot s}$ - The permeability constant of electrons (according to [9]).

$\mu = 2.7 \cdot 10^{-4} \ \frac{m^2}{V \cdot s}$ - The permeability constant of ions (according to [6]).

Ions move 185 times slower than electrons. Therefore, they accumulate in the gap between the electrodes, and create an "ionic cloud" that is negatively charged. This «ionic cloud" impedes the airflow in the medium.

One of the ways to minimize this effect is to give the ions a high initial speed so that they continue on their path and do not accumulate or attach themselves to other molecules.

2.2 Increasing the ionic wind speed by increasing the initial ion speed in the medium

This purpose of this experiment was three-fold:

- **To prove that an "ionic cloud" existed by blowing or pumping air into the system and seeing if there was a change in current.**
- **To check if the speed of the ionic winds could be increased by blowing air into the system.**
- **To find an optimal voltage that simultaneously increases current and air velocity, without creating a big "ionic cloud".**

Experimental setup: The top corona electrode was made of a 4.5*cm* long sewing needle and placed inside a transparent plastic pipe (length: 40*cm*, external diameter: 8*cm*, wall width: 0.5*cm*). Serving as the bottom electrode, a metal net with 1x1cm^2 squares and a wire of 1*mm* diameter was placed 1.2*cm* from the edge of the needle (fig. 1).

Air was injected through the top of the device using a DC fan placed on flexible plastic tubing attached to the ion motor. Testing was performed with air speeds of about $0.32\, {m}/{s}$ and about $0.81\, {m}/{s}$.

The relative increase in the corona flow is δ_I

$$\delta_I = \frac{I_v - I}{I} \cdot 100\%$$

(2) Description:

I - Current measured without external air injected into the system.

I_v - Current measured with external air injected into the system at speed v.

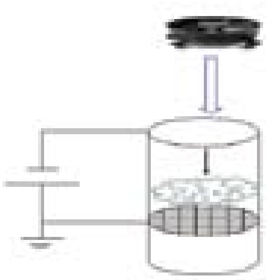

Fig. 1- The position of the DC fan above the ion motor. The fan disperses the “ionic cloud” formed between the electrodes. Results are shown in figure 2.

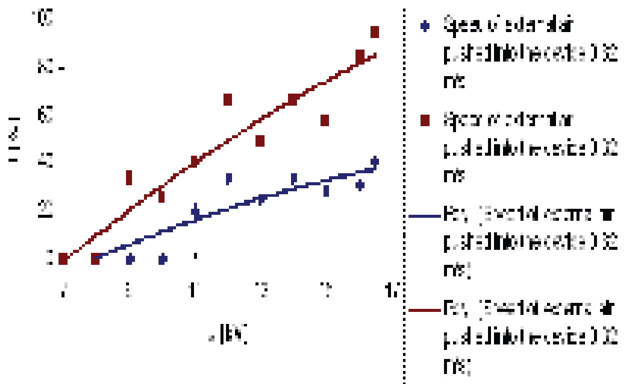

Fig 2- Results. The percent of increase of the current at different speeds of external air pushed into the device.

The results of the experiment show a correlation between the injection of external air into the system and a significant increase in the electric current. For example, at a voltage of $16.5kV$, when the air was injected with a speed of $0.32\, {m}/{s}$, the electric current increased by $42.1\%\ (170-240\mu A)$, and when air was injected at $0.81\, {m}/{s}$, the current increased by $94.1\%(170-330\mu A)$. This proves the existence of “ionic clouds” that formed in between the electrodes.

3. A system based on a superimposition of two ion motors

In this experiment, we checked the option of placing two ion motors one above the other. We checked the rate of change of the air speed as a function of the voltage and current in between the electrodes:

- **With voltage applied only to the top ion motor (i.e. ionizing the air surrounding it).**
- **Voltage applied to only the lower ion motor.**
- **Voltage applied to both ion motors.**

The experiment (figure 3) is based on two tiers of ion motors affixed to a transparent plastic tube at a distance of $21cm$ one from another. The length of the tube is 44 *cm*, and it has a wall thickness of $0.5cm$. The first motor consists of a thin electrode (length of the needle is $45mm$), and a thick electrode ($10X10mm$ steel net). The distance between the electrodes is $3mm$. The second ion motor is identical to the first.

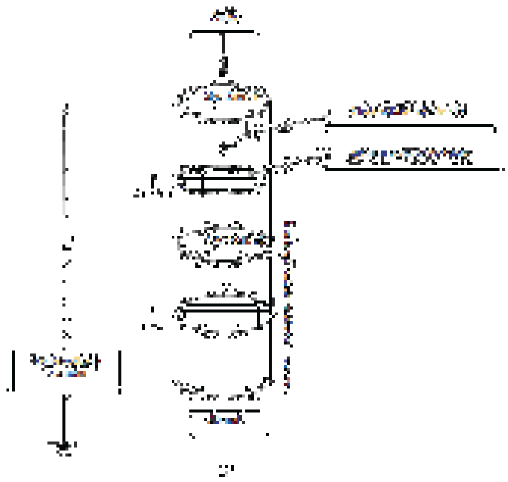

Figure 3. The structure of the two-tier ion motor. The results are displayed in figure 4.

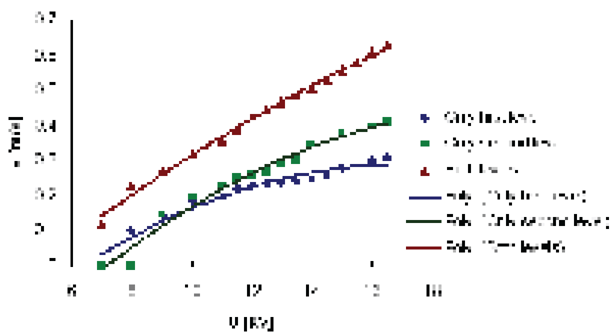

Figure 4. The speed of the ions in the system.

The experiment showed that:

a. The injected air in a combined system led to a significant increase in the speed of the ionic wind – up to an increase of 59%.

b. The rate of increase of the speed of the ionic winds still depends on the increase of the voltage in between the electrodes.

According to the results of these experiments, we calculated the electric power P that existed in the system as a result of the creation of “ionic winds.”

$$P = U \cdot I \quad (3)$$

Description:

I –current in the system.

U –voltage supplied to the system

It should be noted that there is an increase in power when moving from a one-tier to a two-tier system (figure 5).

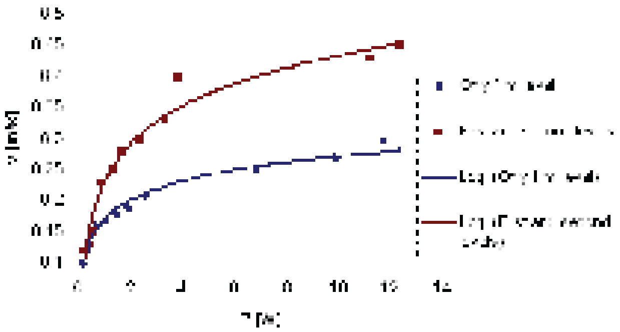

Figure 5. Speed of the ionic winds and the power created in the system.

The experiment proved that the addition of another ion motor decreased the energy needed to create the air-speed. At low air speeds (0.1-0.15*m/s* – and low voltage), the energy saving is negligible and stands at 10%. However, with the increase of voltage, the speed increases to 0.25*m/s*, and there is a five-fold reduction of energy loss. For example, for an air speed of 0.25*m/s*, the necessary power is:

- 6.84*W* – for a one motor system
- 1.3*W* – for a two motor system

The experiment showed that in order to overcome the effect of the “ionic cloud”, a significant amount of energy is necessary. But a system with an additional mechanical device that will disperse the “ionic cloud” with air pressure will lower energy costs.

4. The effect of the distance between the tiers of the ion motor

As with the first experiment, we checked the effect of raising the voltage on the speed of the ionic winds. The following are the results of the experiment. The relative change v[%] as a function of voltage:

$$v[\%] = \frac{v_\Sigma - v_2}{v_2} \cdot 100\% \qquad (4)$$

Description:

v_2 - Rate of increase of the speed of the ionic winds when the system is operating with only the second ion motor.
v_Σ - Rate of increase of the speed of the ionic winds when the system is operated with both levels of ion motors.
The results of the rounded calculations of the relative change in the speed as a function of voltage are presented in figure 6.

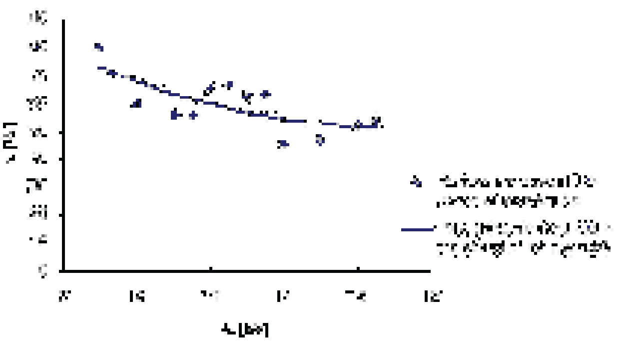

Figure 6. The rate of relative increase in the speed of ionic winds.

The graph indicates that the increase in the voltage of the electrodes lowers the efficiency of the ion motor. In order to clarify the reasons for the decreased efficiency, we conducted research on the effects of the interaction of the two motors. This experiment focused on measuring the change in the speed of the ionic winds at different distances between the levels (ranging from 3 to 23*cm*). The measurements were taken at voltages ranging between 10 and 16*kV*.
The results of the change of speed of the ionic winds as a function of the distance between the motors is presented in figure 7.

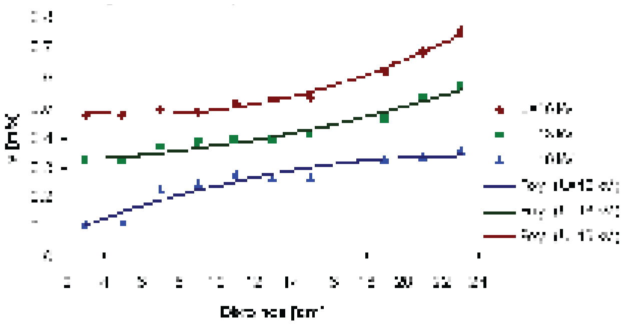

Figure 7. The change of speed of the ionic winds as a function of the distance between the tiers of the ionic motor.

The results clearly indicate the distance between the tiers have a significant effect on the speed of the ionized air. As the distance was increased from 2 till 23*cm*, the speed of the ionic wind increased:

- **At a voltage of 16 kV, the speed increased from .48 to .76 m/s**
- **At a voltage of 13 kV, the speed increased from .33 to .57 m/s**
- **At a voltage of 10 kV, the speed increased from .11 to .36 m/s**

In addition, it should be noted the rate of increase of the ionic winds was greater in lower voltages:

- **At a voltage of 16*kV* – up to an increase of 58.3%**
- **At a voltage of 13*kV* – up to an increase of 72.7%**
- **At a voltage of 10*kV* – up to an increase of 227.3%**

This increase can be attributed to the effect of the electric field in between the levels. This advantage of the influence of the electric field can be used by combining several tiers of ion motors in a series formation as well as increasing the density of the corona electrodes. These measures are meant to minimize the negative interaction of the adjacent tiers of ion motors. It should be noted that there are numerous possibilities for building a multi-tier ion motor. Such experimentations require separate research.

5. Superimposition of several ion motors

Research done with two superimposed ion motors showed an increase in ionic winds and reduced energy consumption. The following experiments checked whether the speeds increased when additional tiers of ion motors were added. A four-tier ion motor was constructed as showed in figure 8.

Similar to the single and double tier ion motor, this system is built of a transparent plastic tube of 75*cm* length, external radius of 8*cm*, and wall width of 0.5*cm*, with a distance of 15*cm* between each level. Every level includes a thin electrode and a thick one (the thin – a sewing needle of 4.5*cm* and the thick one – a steel net of 10x10 mm). The distance between the electrodes (the needle and the net) is 1.2*cm*.
During the experiment, the speed of the air and the current was measured as a function of the voltage under the following conditions:

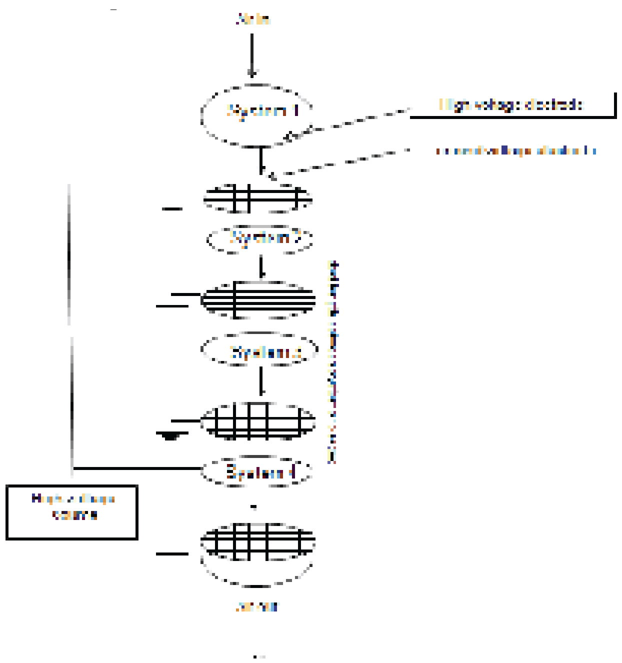

Figure 8. A diagram of a four-stage ion motor.

1. **Only one active ion motor (the fourth level)**
2. **Three levels of active ion motors (the first, the third and the fourth)**
3. **All four levels are active.**

The speeds of the ion winds in a multi-tier system as a function of the voltage is presented in figure 9.

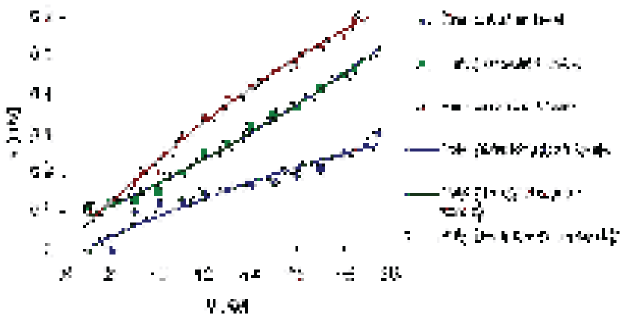

Figure 9. The speed of the ion winds in the multi level system as a function of the voltage.

The relation between the speed of the air as a function of the power used in the system is displayed in figure 10.

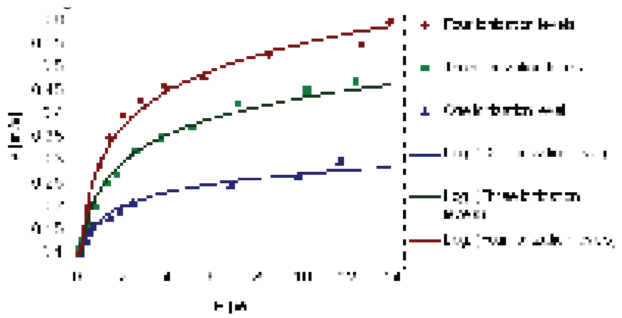

Figure 10. The speed of the air as a function of the power usage in a multi-tier ion motor.

Findings of the experiment with the multi-tier ion motor:

A. In a multi-tier system, there are useful results (flow rates) at much lower voltages than a system with one level.

For example, in a four-tier ion motor, there were useful results at a voltage of 7kV, while a one stage motor required 9kV.

B. The addition of every new ion motor considerably increased the speed of the ion winds. The increase in the speed compared to a one level motor (up to a voltage of 18kV) is:

- For a three-tier motor – an increase in 80%
- For a four-tier motor- an increase in 120%.

Every additional level of ion motors contributed an increase of 40% in the speed of ionic winds.

C. The power consumption decreased with the addition of ion motors to the system. For example, at speeds of 0.3m/s the power usage of an ion motor is:

- o A one tier system – 11.7 W
- o Three tier system – 2.5 W
- o Four tier system - 1W.

D. One can hypothesize from these results, that there is a possibility that with the expansion to several tiers, the speed will continue to increase and the energy consumption will continue to decrease.

6. Equipment

The energy source in all of the experiments was a DC voltage source with a range of 0-20*kV*, and a current of up to 2 [mA] (high voltage power supply code Sn 234455-01 Glassman U.S.A). The voltage and current on the surface of the electrodes was measured by the voltmeter and ammeter built in to the voltage source (high voltage prob code 61010). The air speed was measured by a standard wind meter (code Sn 01708103 Testo 417 Germany).

7. Advantages of ion motors from a perspective of environmental protection

The air we breathe is saturated with many pollutants, such as smoke, soot, aerosol, dust, pollen, fungi, and bacteria that cause irritation, infection, and allergic reactions.

The American Environmental Protection Agency declares that pollutant particles smaller than 10 microns are our biggest health risk (causing heart and blood vessels diseases in addition to lung cancer), because biological protection systems do not cope well with these pollutants, which are usually smaller than 0.1 microns [6].

Ionized air can help reduce the contamination of the air. Pollutants are big molecules that are usually positively charged. Electrons and negative ions from ion motors neutralize the positive charge on pollutants, which then drop out of the air leaving behind a cleaner environment.

The ion balance in the air ranges between 1000-5000 p/cm^3 in outdoors air. In a closed space, this balance drops to a few hundred p/cm^3 or even less. An ion motor could ensure a healthy balance of ions in the air.

Besides the advantage of the reducing energy consumption and the use of polluting fuels, the ion motors may help create a healthier working or living environment.

8. Summary and Conclusions

In the past, the development of ion motors was hindered by their low air velocities. Researchers tried to increase the speed by increasing the electrical field by increasing the voltage. This failed to increase the speed because the higher voltage caused a bigger "ionic cloud" which obstructed the path of the ionic winds. In this research, it was discovered that the problem of the "ionic cloud" can be overcome by injecting air into the medium between the electrodes to disperse the cloud. Doing so led to a significant increase in the speed of the ion motors.

In addition, the research discovered that the air could be injected by placing another ion motor on top of the first one. Adding additional motors to the overall motor system increased the speed of the motor even more. The system of multi-tier ion motors also lowered the power usage of the ion motors and increased their efficiency. The results depended on placing the tiers of ion motors at an optimal distance from one another so as to avoid the negative effects of the motors' interaction.

This technology can help create more efficient cooling fans, pumping, and compressing systems with lower energy consumption and increased health benefits.

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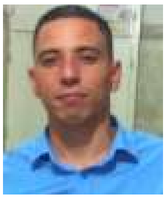

אורן אמסלם

רוני שוורץ

אורן אמסלם ורוני שוורץ

סטודנטים מצטיינים ממכללת סמי שמעון באשדוד, שנה רביעית במגמת הנדסת חשמל זרם חזק שנה רביעית.

בקיץ של שנה שעברה השתתפו בצוות מיוחד במכללה שפיתח טכניקה לשיפור נצילות הספק של מנוע קורונה, שהינו מנוע ללא רוטור או חלקים מכאניים אחרים, הפועל על זרימת לחץ אוויר הנוצר באמצעות חשמל במתח גבוה.

את הממצאים הציגו השניים בכנס השנתי של התאגדות מהנדסי חשמל ואלקטרוניקה 2011 באילת ואף זכו במלגת הצטיינות משר התשתיות ד"ר עוזי לנדאו.

במקביל ללימודים השניים מתנדבים בקהילה. אורן – חונך נוער במצוקה במסגרת אימפקט ורוני - מעביר שיעורי עזר לסטודנטים במכללה, כמו כן מתנדב במס' ארגוני נוער (ראה בקו"ח).

אורן כיום עובד בחברת אלמור תכנון לוחות חשמל. רוני עתיד לחזור בקיץ הקרוב, לשירות צבאי בקבע, כקצין מודיעין.